RECLAMATION
Managing Water in the West

Continuation of Field Research on Advanced Coatings for Mussel Control

Research and Development Office
Science and Technology Program
(Final Report) ST-2018-7089-01

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

August 2018

Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
T1. REPORT DATE: 07/2018	**T2. REPORT TYPE:** RESEARCH	**T3. DATES COVERED**
T4. TITLE AND SUBTITLE Continuation of Field Evaluations on Advanced Coatings for Mussel Control		**5a. CONTRACT NUMBER** XXXR4524KS-RR4888FARD160130006 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER** 1541 (S&T)
6. AUTHOR(S) Allen Skaja Ph.D. Coatings Specialist Bureau of Reclamation Technical Service Center Materials Engineering and Research Laboratory askaja@usbr.gov 303-445-2396		**5d. PROJECT NUMBER** ST-2018-7089-01 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER** 86-68540
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Allen Skaja Ph.D. Coatings Specialist Bureau of Reclamation Technical Service Center Materials Engineering and Research Laboratory		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research and Development Office U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007		**10. SPONSOR/MONITOR'S ACRONYM(S)** **R&D:** Research and Development Office **BOR/USBR:** Bureau of Reclamation DOI: Department of the Interior **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** ST-2018-7089-01

12. DISTRIBUTION / AVAILABILITY STATEMENT
Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 words)* This report is a continuation of field testing of coatings for mussel control. The goals of the past three years was to:

1. Continue evaluating commercially available foul release materials that have been proven to work in previous research.
2. Continue evaluating new products or experimental products that may represent advancements in technology through the use of Material Transfer Agreements (MTA).
3. Continue evaluating the scaled-up coated trashrack panel.

15. SUBJECT TERMS Invasive Mussel Control, Quagga Mussels, Zebra Mussels, Foul Release Coatings, Fouling Prevention

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT** U	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Allen Skaja
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U			**19b. TELEPHONE NUMBER** 303-445-2396

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

BUREAU OF RECLAMATION

Research and Development Office
Science and Technology Program

Materials and Corrosion Laboratory 86-68540

(Final Report) ST-2018-7089-01

Continuation of Field Evaluations on Advanced Coatings for Mussel Control

ALLEN SKAJA Digitally signed by ALLEN SKAJA
Date: 2018.08.31 12:30:24 -06'00'

Prepared by: Allen Skaja, Ph.D.
Protective Coatings Specialist, Materials and Corrosion Laboratory, 86-68540

STEPHANIE PROCHASKA Digitally signed by STEPHANIE PROCHASKA
Date: 2018.09.05 08:26:02 -06'00'

Checked by: Stephanie Prochaska, M.S.
Materials Engineer, Materials and Corrosion Laboratory, 86-68540

RICHARD PEPIN Digitally signed by RICHARD PEPIN
Date: 2018.09.05 09:14:50 -06'00'

Technical Approval: Richard Pepin, PCS,
Protective Coatings Specialist, Materials and Corrosion Laboratory, 86-68540

WILLIAM KEPLER Digitally signed by WILLIAM KEPLER
Date: 2018.09.05 10:43:10 -06'00'

Peer Review: William Kepler, Ph.D., P.E.
Supervisor, Materials and Corrosion Laboratory, 86-68540

For Reclamation disseminated reports, a disclaimer is required for final reports and other research products, this language can be found in the peer review policy:
This document has been reviewed under the Research and Development Office Discretionary peer review process https://www.usbr.gov/research/peer_review.pdf consistent with Reclamation's Peer Review Policy CMP P14. It does not represent and should not be construed to represent Reclamation's determination, concurrence, or policy.

Acknowledgements

We'd like to thank the Bureau of Reclamation (Reclamation) Research and Development (R&D) Office - Science and Technology (S&T) Program for funding this research. We'd also like to thank the Bureau of Reclamation Lower Colorado (LC) Region, the LC Dams Office, and the staff at Parker Dam for all of their in-kind contributions, access, and support.

Acronyms and Abbreviations

Bureau of Reclamation, Reclamation

Foul Release Coatings, FRC

Lower Colorado, LC

Material Transfer Agreements, MTA's

Materials and Corrosion Laboratory, MCL

Pacific Northwest National Laboratory, PNNL

Pittsburgh Paint and Glass, PPG

Research and Development, R&D

Science and Technology, S&T

Executive Summary

Invasive mussels are a nuisance mollusk that attach to submerged surfaces. They also attach to hydraulic structures and can impair their function.

One approach to prevent or reduce the effects of mussel buildup (fouling) is to use antifouling or foul release coatings (FRC). Antifouling coatings contain a biocide that is designed to deter fouling. Foul release coatings rely on physical properties of the coating to impair adhesion of the mussel to the coating surface.

This report summarizes test results from testing performed from 2015 to the present. These results are part of the ten year research and testing program started in 2008 performed by the Materials and Corrosion Laboratory (MCL) researchers on antifouling and foul release coatings to deter mussel fouling. Parker Dam, at Lake Havasu Reservoir on the border between Arizona and California is the field test site to evaluate materials and coatings in low-flowing and flowing exposure conditions. Several types of test panels, including a large mock-up of a trashrack panel are submerged at this location to test newly formulated and existing commercial coatings for resistance to mussel fouling and durability. The trashrack was coated with four commercial FRC, Intersleek 970, Sigmaglide 890, Sher-Release, and Seaspeed V5 to better model an actual submerged structure common in many reservoirs to determine if the softer silicone coatings were durable enough to last long term.

Refer to the ***Background*** section of this report for a summary of prior testing and a table of all previous reports related to this program. Ten peer reviewed reports have been prepared to date to document test results.

The present work is a summary of the past three year's research, which was to:

1. Continue evaluating commercially available foul release coatings proven to work in previous research.
2. Continue evaluating experimental formulated products that may represent advancements in technology through the use of Material Transfer Agreements (MTA).
3. Continue evaluating the full sized coated trashrack panel.

Ten commercial coating systems and one metal alloy are still performing well. The commercial coating systems primarily rely on silicone foul release technology. The metal alloy is based on copper. Four commercial coating systems were removed from the test program because of poor performance.

Inspections showed that for the commercial FRC, fouling began with algae. The algae subsequently allowed for the attachment of mussels. In other words, the fouling builds up and the coatings are no longer self-cleaning under the test conditions (flowing water). However, the algae and mussels were easily removed.

In addition, we expanded existing MTA's with 2 partners to begin evaluation of a total of 23 new, non-commercial products. Nine of 13 new formulations from one partner are performing

well, and 5 of 10 new formulations from another partner are performing well. Both of these MTA partners have formulations that are more durable than the commercially available foul release coatings.

We also signed 3 new MTA's with new partners. Unfortunately, none of these new formulations from them performed well.

The test trashrack has been in the reservoir for 3 ½ years and was also inspected. It was previously coated with three silicone based FRC and one silicone-epoxy hybrid coating All the coatings are performing well, although there was some coating damage to the bars where the trashrake glides on the surface. The weight of the trashrack caused cracking and chipping of the coatings. The hard silicone epoxy hybrid had significantly more corrosion on the leading edge of the Seaspeed V5 than the soft FRC.

Results of tests conducted at the test site at Parker Dam are very informative and are key to determining actual field performance of these coating systems. Evaluating coatings at this site should continue. Possible performance improvement of any experimental or new commercial product is only theoretical until proven by field testing for the efficacy of mussel control. Reclamation should continue to support the development of new materials with MTA partners, and field test the new formulations to help improve technologies. The partners have demonstrated durable formulations that perform well in field testing.

Contents

Tables

Figures

Count all pages that come before this (Cover Page is 1)

Background

In 2007, quagga mussels were discovered in Lake Mead and subsequently downstream from Hoover Dam. The mussels can tightly adhere to submerged surfaces and can impair function of some hydraulic structures. One approach to prevent or reduce the effects of mussel buildup (fouling) is to use antifouling or FRC. Antifouling coatings contain a biocide (poison) that is designed to deter fouling. FRC's rely on physical properties of the coating to impair adhesion of the mussel to the coating surface.

In 2008, Reclamation began to evaluate coatings for mussel control at Parker Dam. This site was selected because samples could be easily set along the face of the dam and across the trashrack structure for two different exposure conditions—flowing water and quasi-static water. Service environments at Reclamation facilities present some unique challenges that must be considered when evaluating coatings for fouling control: highly variable water quality and abundant waterborne materials that affect durability, including sediment, woody debris, vegetation, ice, and other debris.

Most of the commercial products tested are designed for fouling control in the marine shipping industry. Ships are recoated every five to six years. Unfortunately, Reclamation's structures are less accessible, requiring coatings to have a longer service life. Therefore, durability is a primary factor in evaluating materials and coatings. Prior to the emergence of quagga mussels, Reclamation did not have a compelling need for materials and coatings to address fouling problems.

Initial results showed that continuously flowing water along the trashrack structure led to faster fouling rates than areas under quasi-static conditions like those found near the dam face. Reclamation concluded that antifouling coatings were not effective in flowing water but were effective in quasi-static water. This also showed that results from previous research done by other agencies had misleading results because they only evaluated coatings in static conditions.[1,2,3]

Summary of Prior Testing Related to This Report

Report ST- 2015-7095-01 Coatings for Invasive Mussel Control – Final Report evaluated over 100 materials and coatings under field conditions to determine the types of materials/coatings that prevent mussels from adhering to surfaces.[4] Results from this report showed:

1. Mussel fouling is faster under flowing water conditions.
2. Foul release coatings appeared to be the best option for controlling mussel fouling.
3. Copper and copper alloys can work for antifouling, but efficacy depends upon water chemistry, flow rates, and the corrosion rate of the alloy. Performance of copper alloys may vary between facilities, so it is important to fully evaluate site specific conditions prior to deciding whether to use a copper alloy.
4. Antifouling coatings worked in quasi-static water, but not in constantly flowing water.

5. Durable, hard hybrid coatings (Jotun Sealion Resilient and formulations from 2012-MTA-8-1003) showed promise as we were closing out this project, justifying the project's continuation.

Silicone FRC were the best option for mitigation. However, concerns regarding durability prompted a new research project that involved applying silicone FRC on a trashrack panel to determine if the soft coatings would hold up to real-world conditions. ***Report ST-2015-5270-1 Foul Release Coatings Scale up Testing – Parker Dam Trashrack*** evaluated three commercially available silicone FRC and one hard epoxy silicone hybrid.[5] After 18 months of exposure the results showed:

1. The three silicone foul release systems had less damage than the hard silicone epoxy hybrid.
2. The three silicone foul release systems had minimal algae on the surface with no attached mussels.
3. The hard silicone epoxy hybrid had heavier fouling than the silicone foul release systems.

All reports describing coating evaluations performed by the Materials and Corrosion Laboratory (MCL) to reduce fouling from mussels conducted over the last ten years (2008-2018) are listed in Table 1.

Table 1. All reports on mussel related studies conducted by the Materials and Corrosion Laboratory Researchers 2008-2018.

	Titles	**Year(s)**	**Report Number**
1	Mussel adhesion mechanism	2011	MERL-2011-21
2	Investigation of molybdenum and tungsten disulfide for mussel control	2011	MERL-2011-37
3	Overcoating coal tar enamel using FRC	2011	MERL-2011-41
4	Natural biocides for zebra and quagga mussel control	2011	MERL-2011-46
5	Advanced review of mussel adhesion	2013	MERL-2013-43
6	Durable FRC	2012-2013	MERL-2014-57
7	Coatings for invasive mussel control	2008-2015	ST- 2015-7095-01
8	FRC scale up testing – Parker Dam trashrack	2013-2015	ST-2015-5270-1
9	Durable silicone FRC CRADA	2014-2016	ST-2016-0809-01/ 8540-2016-02
10	Continuation of field evaluations on advanced coatings for mussel control	2015-2018	ST-2018-7089-01

Present Testing

Work conducted over the past three years is a continuation of previous research which was to:

1. Continue evaluating commercially available foul release materials that were shown to work in previous research.
2. Continue evaluating experimental products that may represent advancements in technology obtained for testing using a Material Transfer Agreements (MTA).
3. Continue evaluating the coated trashrack panel.

Exposure Conditions

Parker Dam, at Lake Havasu Reservoir on the border between Arizona and California (Figure 1), was selected as the field test site to evaluate materials and coatings in quasi-static (low-flowing) and dynamic (flowing) exposure conditions. Mussels at this location on the lower Colorado River reproduce almost year-round and have more reproductive cycles per year than northern climate infestations.

For each coating system tested, three one-square foot steel plates were used in quasi-static exposure. They were secured by a nylon rope and lowered approximately 50 feet (ft.) into the water near the face of the dam. For the dynamic conditions, one 18-inch (in.) by 24-in. coated floor grate with 1-in. spacing was lowered to a depth of approximately 40 ft. below the water's surface. The samples were hung downstream from the forebay trashrack structure. For velocity measurements and water temperature changes refer to report ST-2015-7095-01.**Error! Bookmark not defined.**

Figure 1. Aerial photo of Parker Dam, CA. The red line indicates the location where the plates were placed, and the yellow line indicates where the grates were placed.

Results and Discussion

Commercially Available Systems

Table 2 lists the coating systems that are still being tested. Most of the FRC systems are no longer foul resistant and have accumulated fouling on the surface, however, the fouling is easily removed with minimal force (no measurable force using a force gauge). All samples, including those with complex geometries, have minimal corrosion after ten years of exposure, indicating they are durable. Figures 2 and 3 show an example of fouling buildup on the silicone FRC subject to dynamic exposure after 5 and 10 years, respectively.

Z-Alloy, a copper alloy, was added to the study in May 2015 and is still being tested. Z-Alloy can be made into intakes and fish screens. No mussels have attached to the test specimens in either quasi-static or dynamic conditions after three years of exposure. Figure 4 shows a Z-Alloy fish screen after two years of exposure.

During the course of this study, some coating systems were removed from testing. These coatings are listed in Table 3. Fuji Film Smart Surfaces was one of the first systems selected for testing at the beginning of the study in May 2008 and was performing well. However, Fuji went out of business in December 2015, thus all Fuji systems (also co-branded as Sherwin Williams Sher-Release) were removed from testing in May 2016.

Sherwin Williams Polysiloxane XLE-80 and PPG PSX 700 systems are designed for atmospheric service and were evaluated since they have graffiti resistance properties. Both systems were removed from testing because they didn’t perform well against mussel fouling (Figures 5 and 6). Sharkskin, a micro/nano texturing polymeric film, (said to mimic shark skin) was evaluated. It was removed from testing in April 2018 due to poor performance (Figure 7).

Table 2. Commercially available coatings and metal alloys in testing as of this publication date.

Coating System/ Metal Alloy	Dates of Exposure	Comments from April 2018 inspection
International Paint Intersleek 970	May 2008 to present	Dynamic: ½" thick biofouling primarily algae, easily cleaned Quasi-static: No mussels
CMP Bioclean SPG-H	October 2009 to present	Dynamic: ½" thick biofouling primarily algae, easily cleaned Quasi-static: some mussels attached to algae, easily cleaned
PPG Sigmaglide 890	October 2009 to present	Dynamic: minimal biofouling primarily algae, easily cleaned Quasi-static: No mussels
Hempel Hempasil X3	December 2012 to present	Dynamic: ½" thick biofouling primarily algae, easily cleaned Quasi-static: No mussels
International Paint Intersleek 425	December 2012 to present	Dynamic: Lost coated grate Quasi-static: No mussels
Nusil 9707	May 2012 to present	Dynamic: ½" thick biofouling primarily algae, easily cleaned Quasi-static: Few mussels, easily cleaned
Jotun Sealion Repulse	May 2013 to present	Dynamic: minimal biofouling primarily algae, easily cleaned Quasi-static: No mussels
Jotun Sealion Resilient	May 2013 to present	Dynamic: ¾" thick biofouling primarily algae, easily cleaned Quasi-static: Many mussels, not as easily cleaned as the silicones
Silicone Solutions F-23	December 2014 to present	Dynamic: ½" thick biofouling primarily algae, easily cleaned Quasi-static: few mussels, easily cleaned
Silicone Solutions SS5000A	December 2014 to present	Dynamic: ¾" thick biofouling primarily algae, easily cleaned Quasi-static: few mussels, easily cleaned
Z-Alloy	May 2015 to present	Dynamic: no mussels attached, but mussels are caught up in turbulence due to attachment to floor grate. Quasi-static: no mussels present

Table 3. Coating systems evaluated, but removed from testing

Coating System	Dates of Exposure	Comments from time of removal
Fuji Film Smart Surfaces (also referred as Sherwin Williams Sher-Release)	May 2008 to May 2016	No fouling, removed due to company no longer manufacturing product
Sherwin Williams Polysiloxane XLE-80	May 2015 to December 2015	Dynamic: Heavy mussel fouling, difficult to remove fouling Quasi-static: Heavy mussel fouling, difficult to remove fouling
PPG PSX 700	May 2015 to December 2015	Dynamic: Heavy mussel fouling, difficult to remove fouling Quasi-static: Heavy mussel fouling, difficult to remove fouling
Sharkskin	July 2017 to April 2018	Dynamic: Heavy mussel fouling, difficult to remove fouling Quasi-static: Heavy mussel fouling, difficult to remove fouling

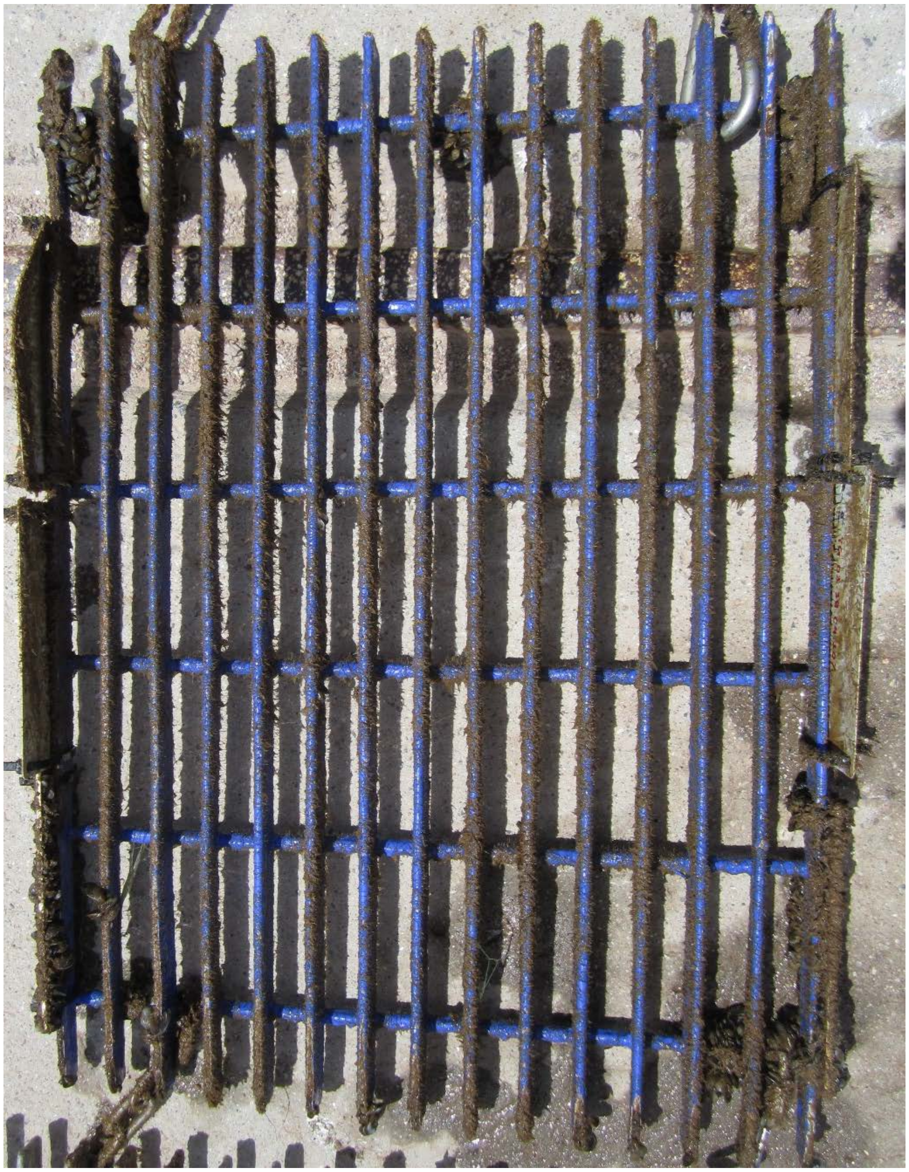

Figure 2. International Paint Intersleek 970 at five years' exposure in dynamic conditions, photo taken May 2013.

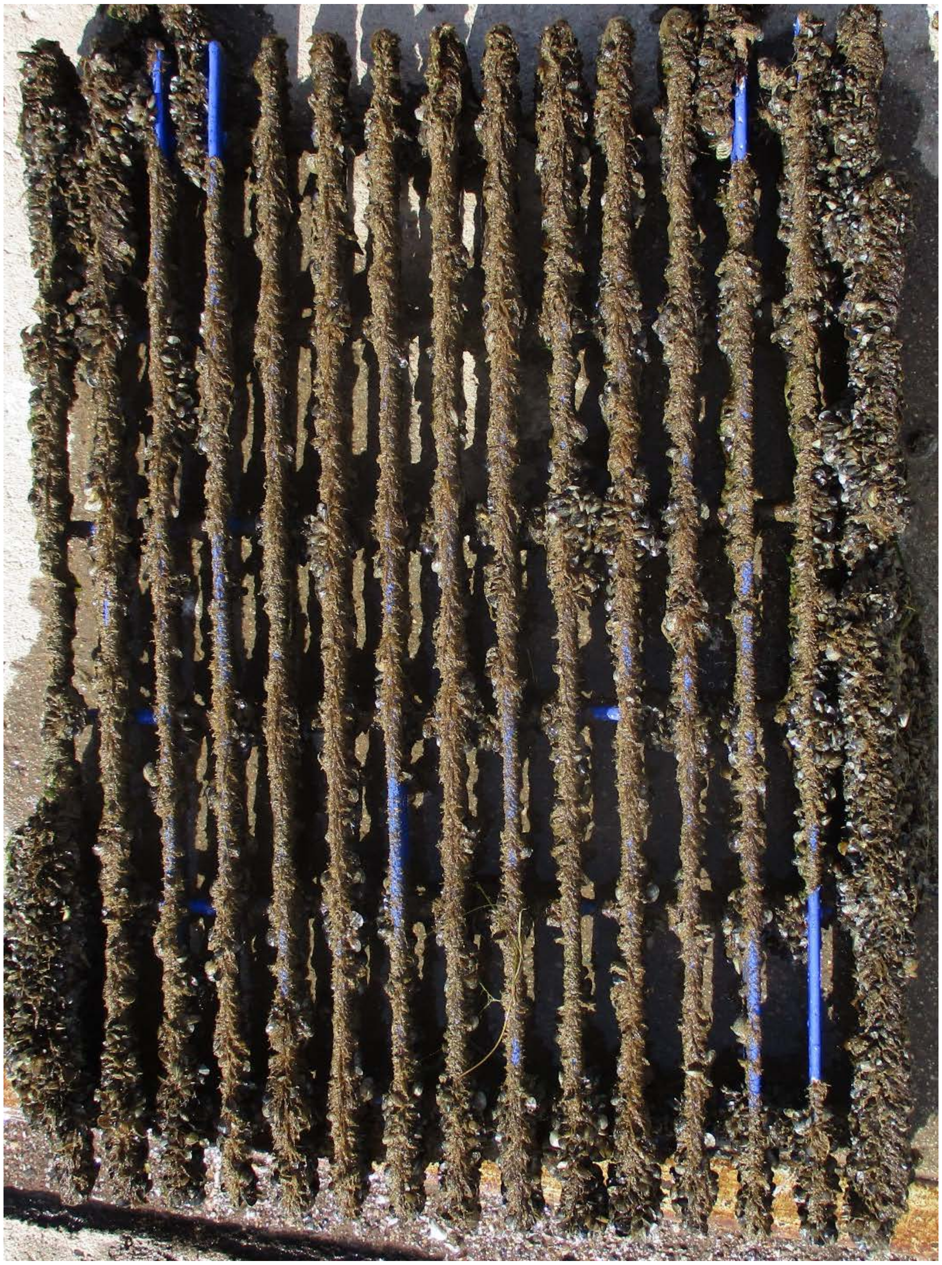

Figure 3. International Paint Intersleek 970 after 10 years' exposure in dynamic conditions, fouling is easily removed, photo taken April 2018.

Figure 4. Z-Alloy in dynamic exposure after two years' exposure, photo taken July 2017.

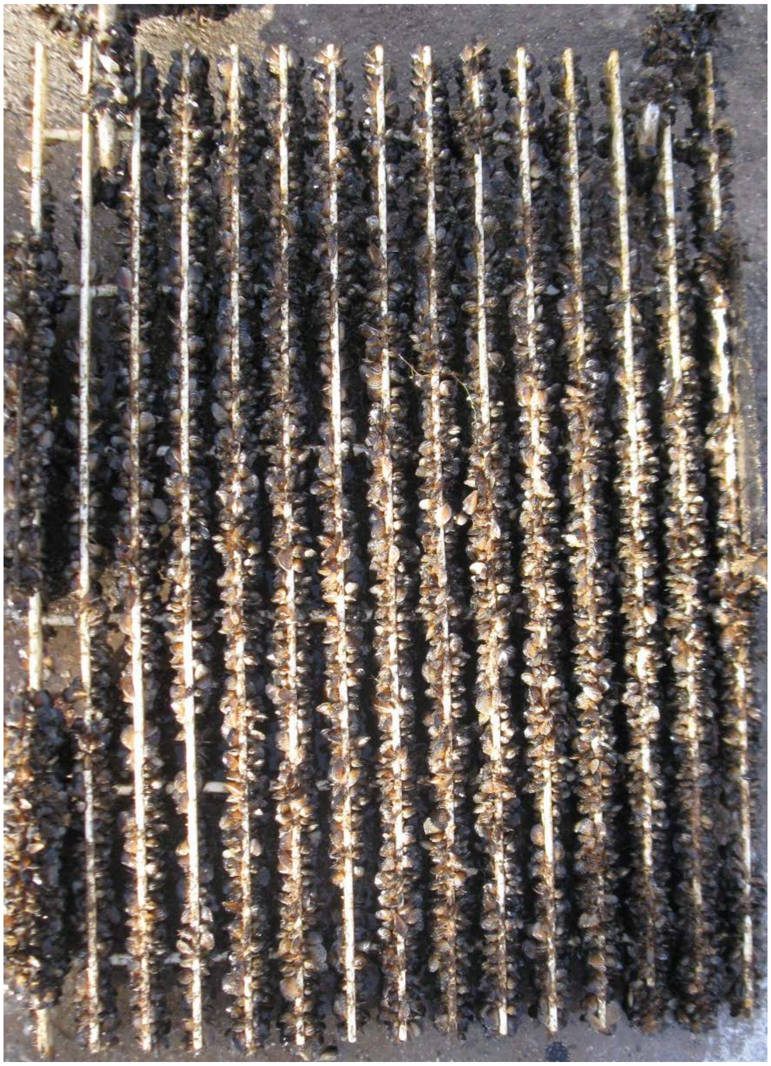

Figure 5. Sherwin Williams Polysiloxane XLE-80 in dynamic exposure, photo taken December 2015.

Figure 6. PPG PSX 700 in dynamic conditions, photo taken December 2015.

Figure 7. Sharkskin in dynamic exposure after nine months' exposure, photo taken April 2018.

Experimental Systems

MTA's were set up with each company to evaluate each partner's experimental formulations. MTA's are designed to protect intellectual property while allowing us to perform evaluations about whether the coating is successful at preventing mussel attachment. After the MTA's were signed, partners sent samples to Reclamation researchers to be installed at the Parker Dam test site. Periodic inspections were conducted to evaluate the effectiveness of each experimental coating and travel reports were written to document observations and sent to the MTA partner.

MTA partner 2012-MTA-8-1003 utilized this arrangement to further advance their technology by verifying formulation reproducibility and advancing new formulations of durable foul release technology. The partner has submitted materials for three different rounds of testing. Some were also summited to determine reproducibility of results and are shown in Table 4. Many of the experimental formulations perform as well as the commercial FRC.

Figure 8 shows C4-20% after three years of flowing water exposure. The coating surface remains mussel free while the surrounding area has significant mussel buildup. The panels were secured by zip ties and the mussels fouled the zip ties.

Table 4. Experimental formulations from Material Transfer Partner 2012-MTA-8-1003

Experimental Formulation	Dates evaluated	Comments for dynamic exposure
A-10%	December 2012 to May 2014	100% covered, not as easy to clean as commercial FRC after 18 months
A-20%	December 2012 to May 2014	100% covered, not as easy to clean as commercial FRC after 18 months
C-10%	December 2012 to present	100% covered, easily cleaned after 5 ½ years, prevented fouling through 5 years
C-20%	December 2012 to present	100% covered, easily cleaned after 5 ½ years, prevented mussels through 5 years
PDMSA-4/PDMS-16	August 2014 to May 2015	100% covered, not as easy to clean as commercial FRC after 18 months
PDMSA-8/PDMS-12	August 2014 to May 2015	100% covered, not as easy to clean as commercial FRC after 18 months
A4-20%	August 2014 to December 2015	100% covered, not as easy to clean as commercial FRC after 18 months
C4-20%	August 2014 to present	10% covered, as easy to clean as commercial FRC after 3 3/4 years
SO-PMM-0021	August 2014 to present	100% covered, as easy to clean as commercial FRC after 3 3/4 years
SO-PMM-0025	August 2014 to December 2015	100% covered, not as easy to clean as commercial FRC after 18 months
SB-304-9	July 2017 – present	100% covered, not as easy to clean as commercial FRC after 1 year
F12	July 2017 – present	10% covered, as easily cleaned as commercial FRC after 1 year
F11	July 2017 – present	50% covered, not as easy to clean as commercial FRC after 1 year
F6	July 2017 – present	70% covered, as easily cleaned as commercial FRC after 1 year
SO-0021	July 2017 – present	70% covered, as easily cleaned as commercial FRC after 1 year
AMP-GC-R6-5%-2432	July 2017 – present	70% covered, as easily cleaned as commercial FRC after 1 year
F30-IGC-PACM	July 2017 – present	100% covered, as easily cleaned as commercial FRC after 1 year

Figure 8. Partner 2012-MTA-9-1003 formulation C4-20% after three years' dynamic water exposure, photo taken July 2017.

MTA partner 2014-MTA-8-1010 provided ten experimental formulations. Five formulations are performing as well as the commercially available FRC, shown in Table 5. Four other formulations have more fouling buildup than commercially available FRC and are moderately easy to remove. Fouling was difficult to remove from one formulation. Figures 9 and 10 show the latest photos of the specimens coated with these formulations.

Table 5. Experimental formulations from partner 14-MTA-8-1010

Experimental Formulation	Dates tested	Comments for dynamic exposure
14-MTA-8-1010 #1	December 2014 to present	50% covered, as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #2	December 2014 to December 2015	100% covered, moderately easy to clean, not as easily cleaned as commercial FRC after 1 year
14-MTA-8-1010 #3	December 2014 to present	100% covered, as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #4	December 2014 to present	100% covered, as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #5	December 2014 to present	100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #6	December 2014 to present	100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #7	December 2014 to present	100% covered, as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #8	December 2014 to present	100% covered, as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #9	December 2014 to present	100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years
14-MTA-8-1010 #10	December 2014 to present	100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years

Figure 9. Partner 14-MTA-8-1010 formulations 1, 3, 4, 5, & 6 (left to right) after 3 ½ years in dynamic exposure, photo taken April 2018.

Figure 10. 14-MTA-8-1010, formulations 7, 8, 9, 10 (left to right), after 3 ½ years in dynamic exposure, photo taken April 2018.

Additional MTAs provided for more experimental formulations, but mussels attached and were difficult to remove as shown in Table 6. Unfortunately, this means that mussels will build up and the surfaces will never be completely free of fouling.

Figure 11 shows a test specimen coated with the14-MTA-8-1008 (#1) formulation after one year in dynamic exposure. There is extensive mussel buildup on this coating. Figure 12 is a photo of 15-MTA-8-1012 formulation #1 after one year of dynamic exposure. A few mussels attached to the surface and were very difficult to remove, leaving the byssal threads on the coating surface. Figure 13 is a photo of the 15-MTA-8-1013 #1 experimental formulation after six months of exposure. Mussels attached to the surface and required significant force to remove them resulting in breaking their shells. All three of these MTA partner experimental systems were removed from testing in December 2016.

Table 6. Additional MTA partner experimental formulations

Experimental Formulations	Dates Evaluated	Comments
14-MTA-8-1008 #1	12-2015 to 12-2016	100% covered, not easy to clean, after 1 year
15-MTA-8-1012 #1	12-2015 to 12-2016	50% covered, not easy to clean, after 1 year
15-MTA-8-1012 #2	12-2015 to 12-2016	50% covered, not easy to clean, after 1 year
15-MTA-8-1012 #3	12-2015 to 12-2016	50% covered, not easy to clean, after 1 year
15-MTA-8-1012 #4	12-2015 to 12-2016	50% covered, not easy to clean, after 1 year
15-MTA-8-1012 #5	12-2015 to 12-2016	50% covered, not easy to clean, after 1 year
15-MTA-8-1013 #1	6-2016 to 12-2016	100% covered, not easy to clean, after 6 months

Figure 11. 14-MTA-8-1008 #1 experimental formulation after one year of dynamic exposure, photo taken December 2016.

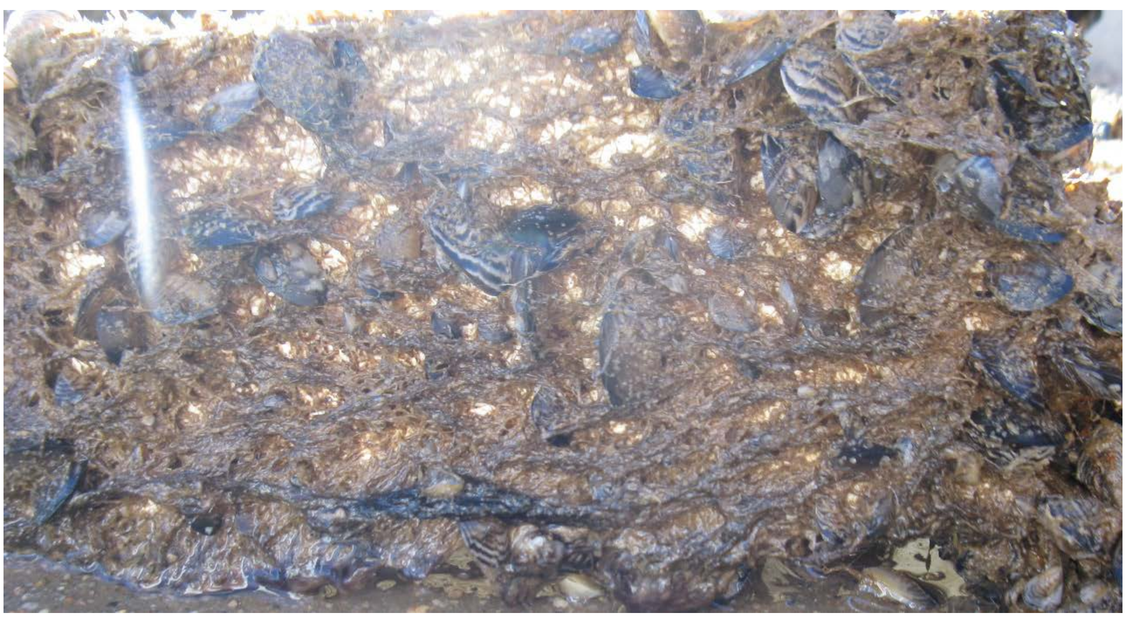

Figure 12. 15-MTA-8-2012 #1 after one year of dynamic exposure, photo taken December 2016.

Figure 13. 15-MTA-8-1013 #1 after one year of dynamic exposure, photo taken December 2016.

Inspection of Trashrack Specimen

The trashrack inspection showed that after three and a half years the three FRC Intersleek 970, Sigmaglide 890, and Sher-Release had minimal fouling (primarily algae) on the surface with damage to the bars where the trashrake glides on the surface. The PPG Sigmaglide 890 and Seacoat Seaspeed V5 had more fouling on the surface due to being in deeper water. The majority of the corrosion was on the leading edge of the bars that contained the hard silicone/ epoxy hybrid Seaspeed V5. The weight of the trashrake caused cracking and chipping of the coating. Figures 14-17 show the condition of the trashrack coatings after 3.5 years while in service.

Figure 14. International Paint Intersleek 970 after 3.5 years exposure, photo taken underwater in July of 2017.

Figure 15. Sigmaglide 890 after 3.5 years exposure, photo taken underwater in July of 2017.

Figure 16. Sherwin Williams Sher-Release after 3.5 years exposure (no longer manufactured), photo taken underwater in July of 2017.

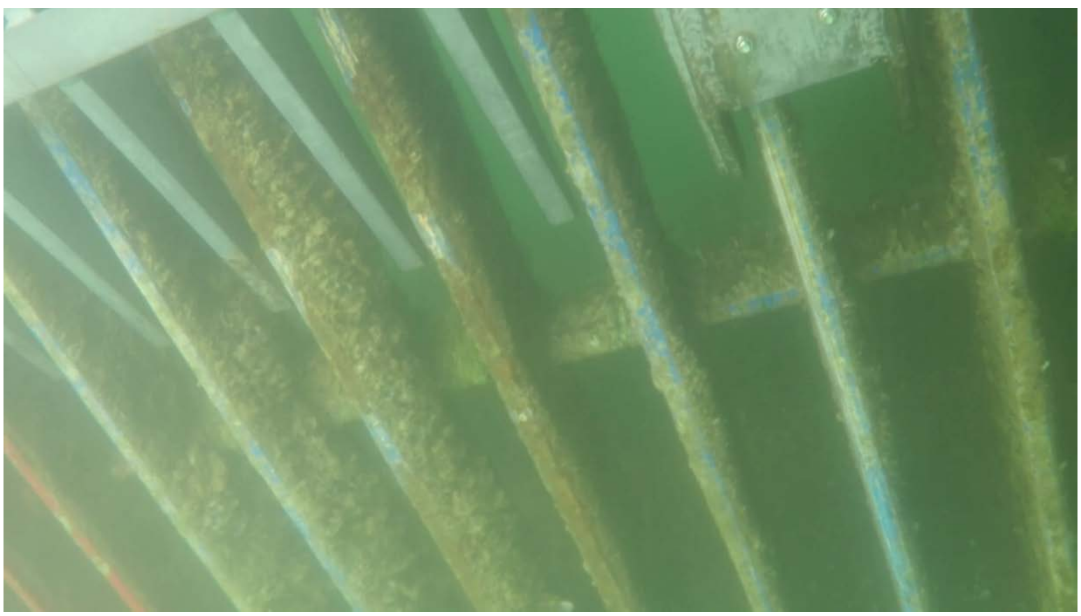

Figure 17. Seacoat Seaspeed V5 after 3.5 years exposure, photo taken underwater in July of 2017.

Conclusions

Commercial FRC began fouling with algae followed by mussels that attached to the algae. The fouling builds up and the coatings are no longer self-cleaning under the test conditions at Parker Dam. However, the fouling could be easily removed from the panels' surface.

MTA partner 2012-MTA-8-1003 developed thirteen additional FRC formulations for evaluation. Nine of the thirteen experimental formulations remain in testing and are performing as well as the commercially available FRC. This partner has patent licenses available for manufacturers to take the products to commercialization.

Another partner, 2014-MTA-8-1010, provided ten experimental products of which five are performing as well as commercially available FRC.

Three new MTA's were signed with three manufacturers that developed experimental products. Unfortunately, none of these experimental products prevented fouling and the fouling was more difficult to remove than the other FRC tested.

The trashrack specimen inspection showed that after three and a half years the three FRC had minimal fouling, (primarily algae) on the surface with damage to only the bars where the trashrake slides on the surface. The PPG Sigmaglide 890 and Seacoat Seaspeed V5 had more fouling due to being in deeper water. The majority of the corrosion was on the leading edge of the bars that contained the hard silicone/ epoxy hybrid. The weight of the trashrake caused cracking and chipping off the coating leading to the corrosion. It was originally thought that the hard silicone hybrid would have been more corrosion resistant than the soft silicone FRC.

Next Steps

Field testing needs to continue in order to advance new technologies. The performance of new products is only theoretical until actual performance has been confirmed by field evaluation for mussel control.

This past year, Pacific Northwest National Laboratory (PNNL) contacted the principle investigator about coatings technology they were developing and wanted to collaborate with Reclamation to have the samples evaluated at the Parker Dam test site. As PNNL develops viable candidates, Reclamation will incorporate them into field testing.

The Army Corps of Engineers also want to study the mussels' adhesion mechanism in detail and wants to perform large scale testing of FRC previously evaluated by Reclamation to determine if they are durable enough for their service conditions. Reclamation has already provided them all the data collected to date and has provided them information about lessons learned. Reclamation will provide support for their efforts and plans to be onsite when they apply the coatings on their infrastructure to make sure they are applied correctly.

In 2018, Reclamation held a prize competition for the public to suggest solutions for mussel eradication. Three coatings-related solutions were submitted that have the potential to prevent mussel attachment and not eradication. These solutions should be investigated at Parker Dam test site as prevention methods.

As new materials are developed with MTA partners or new partners, Reclamation will continue to support the development of their anti-fouling coatings through comprehensive testing to advance the technologies that work. The group of partners has clearly demonstrated many formulations that work in field testing that are more durable than the commercially available FRC.

References

[1] Puzzuoll, F.V., and E.G. Leitch. April 25, 1991. Evaluation of Coatings to Control Zebra Mussel Colonization – Year One – Interim Report, Ontario Hydro Report 91-56-K.
[2] Spencer, F.S. April 1998. Evaluation of Coatings to Control Zebra Mussel Colonization: Year 8 Update, Ontario Hydro Report 344-000-1998-RA-0001-R00.
[3] Race, T.D, and M.A. Kelly. 1997. Zebra Mussels and Aquatic Nuisance Species. Boca Raton: Lewis Publishers. Chapter 23 – A Summary of a Three Year Evaluation Effort of Anti-Zebra Mussel Coatings and Materials: 359-388.
[4] Skaja, Allen, Coatings for Invasive Mussel Control-Final Report, Bureau of Reclamation Report Number ST-2015-7095-01, 2015.
[5] Tordonato, David, Foul Release Coatings Scale up Testing – Parker Dam Trashrack, Bureau of Reclamation Report Number ST-2015-5270-01, 2015.